UNIVERSITY OF CANBERRA

INSTITUTE FOR APPLIED ECOLOGY

BIOLOGICAL RESPONSE TO FLOWS DOWNSTREAM OF CORIN, BENDORA, COTTER AND GOOGONG DAMS

Autumn 2016

Report to Icon Water

APPLIEDECOLOGY.EDU.AU

Prepared for: Icon Water

Produced by:

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Document history and status				
Version	**Date Issued**	**Reviewed by**	**Approved by**	**Revision Type**
Draft	25/6/16	Project team	Ben Broadhurst	Internal
Draft	29/8/16	John Hyam	Ben Broadhurst	External
Final	27/9/16		Ben Broadhurst	

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BACKGROUND AND STUDY OBJECTIVE

- The Cotter and Queanbeyan Rivers are regulated to supply water to the Australian Capital Territory (ACT). Ecological assessment is undertaken in spring and autumn each year to evaluate river response to environmental flow releases to the Cotter and Queanbeyan Rivers. Sites below dams are assessed and compared with sites on the unregulated Goodradigbee River and Queanbeyan River upstream of Googong Dam to evaluate ecological change and responses attributed to the flow regulation.
- This study addresses the needs of Icon Water's License to Take Water (WU67) to assess the effects of dam operation, water abstraction, and environmental flows, and to provide information for the adaptive management of the Cotter and Googong water supply catchments. This study specifically focuses on assessing the ecological status of river habitats by investigating water quality and biotic characteristics.

AUTUMN 2016 RESULTS AND CONCLUSIONS

- Water quality parameters at below dam test sites were within guideline levels in autumn 2016, with the exception of nitrogen oxides (NO_x) and total nitrogen (TN) which were above guideline levels at four of the five and two of the five test sites, respectively. Click here for more information
- All test and reference sites met the environmental flow ecological objective of <20% cover of filamentous algae in riffle habitats. Click here for more information
- Sites CM2 and CM3 (downstream of Bendora Dam and downstream of Cotter Dam, respectively) were the only sites which met the environmental flow ecological objective of AUSRIVAS band A; however all sites except CM3 had relatively high proportions of environmentally sensitive taxa. Click here for more information

  Filamentous algae cover and AUSRIVAS band scores for the test sites (green shading indicates environmental flow objective met, orange shading indicates environmental flow objective not met).

Site	Riffle filamentous algae cover (%)	AUSRIVAS band (O/E score)
CM1 (Corin Dam)	10	B
CM2 (Bendora Dam)	< 10	A
CM3 (Cotter Dam)	< 10	A
QM2 (Googong Dam)	< 10	B
QM3 (Googong Dam)	< 10	B

PROJECT RECOMMENDATIONS

- No new recommendations at this stage. The recommendations from the spring 2014 assessment are still applicable to the autumn 2016 assessment given the results.

INTRODUCTION

Water diversions and modified flow regimes can result in deterioration of both the ecological function and water quality of Australian streams (Arthington and Pusey 2003). Many of the aquatic ecosystems in the Australian Capital Territory (ACT) are subject to flow regulation. Environmental flow guidelines were introduced in 1999 as part of the Water Resources Act 1998 and redefined in 2006 and 2013 (ACT Government 2013). The Environmental Flow Guidelines identify the components of the flow regime that are necessary for maintaining stream health, and set the ecological objectives for the environmental flow regime (ACT Government 2013). The ecological objectives for environmental flows are 1) for the Cotter and Queanbeyan Rivers to reach an Australian River Assessment System (AUSRIVAS) observed/expected band A grade (similar to reference condition) and 2) to have <20% filamentous algal cover in riffles for 95% of the time (ACT Government 2013). Ecological assessment evaluates the effectiveness of the flow regime for meeting the ecological objectives and provides the scientific basis to inform decisions about refinements to future environmental flow releases to ensure that these resources are protected.

This assessment is based on the ecological objectives of environmental flow regimes in the ACT, has been ongoing at fixed sampling sites since 2001 and is based on bi-annual assessments of macroinvertebrate assemblages, algae (periphyton and filamentous algae) and water quality. Sampling is conducted during autumn and spring of each year to evaluate the condition of river habitat downstream of dams on both the Cotter and Queanbeyan Rivers. A comparison is made with the condition of reference sites on the unregulated Goodradigbee River and the Queanbeyan River upstream of Googong Dam.

Tributaries of the Cotter and Goodradigbee Rivers are also sampled to determine whether impacts on biological condition in these rivers is being caused by catchment or river regulation effects. For example, if Cotter River tributaries are assessed in poorer biological condition than reference tributaries on the Goodradigbee River, then catchment condition may be driving instream biological condition at Cotter River test sites regardless of river regulation effects. However, if Cotter and Goodradigbee River tributaries are in similar biological condition, then differences in biological condition between Goodradigbee and Cotter River sites may be attributed to river regulation effects.

This sampling and reporting program satisfies Icon Water's Licence to Take Water (WU67) and the requirement to provide an assessment of the effects of dam operation and the effectiveness of environmental flows. The information from the assessment links into the adaptive management framework applied in the water supply catchments.

This report provides an assessment of sites downstream of the dams on the Cotter and Queanbeyan Rivers in autumn 2016, and focuses on comparisons of these sites with unregulated reference sites and the results of previous assessments. Site summary sheets outlining the outcomes of the autumn 2016 assessment for each of the test sites CM1 (Corin Dam), CM2 (Bendora Dam), CM3 (Cotter Dam), QM2 (Googong Dam), and QM3 (downstream of QM2) are included as Appendix 1.

FIELD AND LABORATORY METHODS

STUDY AREA

The study area includes the Cotter and Goodradigbee Rivers, which are situated to the east and west of the western border of the ACT, respectively, and the Queanbeyan River to the east of the ACT (Figure 1). The Cotter River is a fifth order stream (below Cotter Dam) with a catchment area of approximately 480 km^2. The Cotter River is a major source of drinking water for Canberra and Queanbeyan, with the principal management outcome to ensure a secure water supply (ACT Government 2006). Conservation of ecological values of the river is an important consideration in the ongoing management of the Cotter River. The river is regulated by three dams, the Cotter Dam, Bendora Dam and Corin Dam.

The Cotter River catchment is largely free of pollutants and human disturbance aside from regulation, which provides the opportunity to study the effects of flow releases from the dams with minimal confounding from other factors often present in environmental investigations (Chester and Norris 2006; Nichols *et al.* 2006). The Murrumbidgee to Cotter pumping augmentation (M2C) project has been implemented to provide an environmental flow transfer capability (up to 40ML d^{-1}) for the Cotter River reach below Cotter Dam by pumping water from Murrumbidgee River when releases from the Cotter Dam are unavailable.

The Queanbeyan River is a fifth order stream (at all sampling sites), and is regulated by Googong Dam approximately 90 km from its source to secure the water supply for the ACT and Queanbeyan. Compared to the Cotter River catchment, the Googong catchment is less protected and is therefore subject to disturbance in addition to flow regulation.

The Goodradigbee River is also a fifth order stream (at all sampling sites) and remains largely unregulated until it reaches Burrinjuck Dam (approximately 50 km downstream of the study area). This river constitutes an appropriate reference site for the study because it has similar environmental characteristics (substrate and chemistry) but is largely unregulated (Norris and Nichols 2011).

Fifteen sites were sampled for biological, physical and chemical variables between the 18th and 20th April 2016 (Table 1). Site characteristics including latitude, longitude, altitude, stream order, catchment area, and distance from source were obtained from 1:100 000 topographic maps. Latitude and longitude were confirmed in the field using a Global Positioning System.

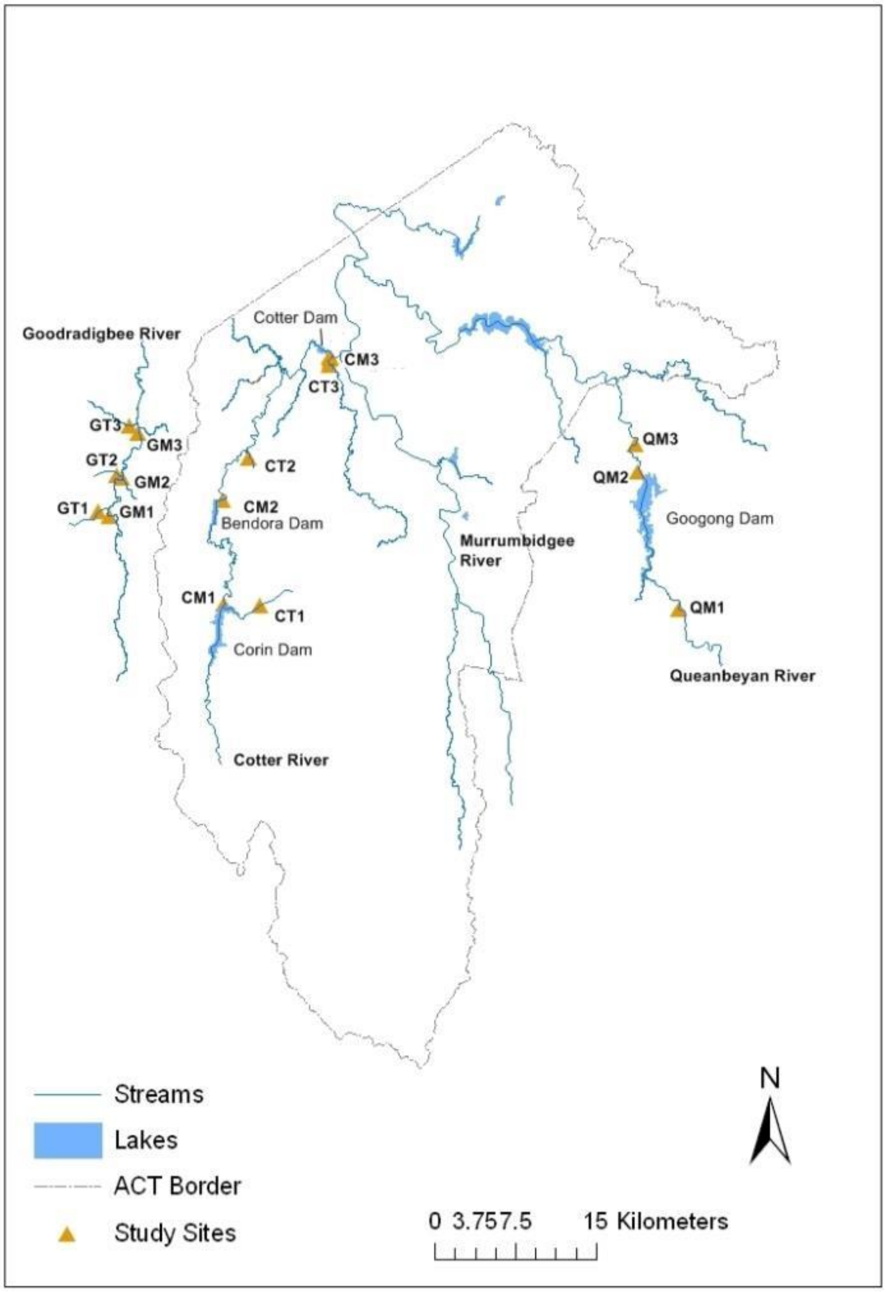

Figure 1. The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program.

Table 1: Cotter, Goodradigbee and Queanbeyan River sites sampled for the below dams assessment program, autumn 2016.

Site	River	Location	Altitude (m)	Distance from source (km)	Stream order
CM1	Cotter	500m downstream of Corin Dam	900	31	4
CM2	Cotter	500 m downstream of Bendora Dam	700	51	4
CM3	Cotter	100m upstream Paddy's River confluence	500	75	5
CT1	Kangaroo Ck	50m downstream Corin Road crossing	900	7.3	3
CT2	Burkes Ck	50 m upstream of confluence with Cotter River	680	4.5	3
CT3	Paddys	500 m upstream of confluence with Cotter River	500	48	4
GM1	Goodradigbee	20 m upstream of confluence with Cooleman Ck	680	38	5
GM2	Goodradigbee	20 m upstream of confluence with Bull Flat Ck	650	42	5
GM3	Goodradigbee	100 m upstream of Brindabella Bridge	620	48	5
GT1	Cooleman Ck	50 m upstream of Long Plain Road crossing	680	17.9	4
GT2	Bull Flat Ck	Immediately upstream of Crace Lane crossing	650	15.6	4
GT3	Bramina Ck	30 m upstream of Brindabella Road crossing	630	18	5
QM1	Queanbeyan	12 km upstream of Googong Dam near 'Hayshed Pool'	720	72	5
QM2	Queanbeyan	1 km downstream of Googong Dam	590	91.6	5
QM3	Queanbeyan	2 km downstream of Googong Dam at Wickerslack Lane	600	92.6	5

HYDROMETRIC DATA

Mean daily flow data for each of the below dam test sites (provided by Icon Water) and Goodradigbee River reference sites (obtained from the NSW Department of Primary Industries Office of Water, gauging station 410088) was used to determine changes in river flow for the months preceding sampling. Daily rainfall data for Canberra was obtained from the Bureau of Meteorology.

PHYSICAL AND CHEMICAL WATER QUALITY ASSESSMENT

Water temperature, pH, electrical conductivity and turbidity were measured at all sites using a calibrated Horiba U-52 water quality meter and dissolved oxygen was measured using a Hach portable DO meter. Total alkalinity was calculated by field titration to an end point of pH 4.5 (A.P.H.A. 2005). Two 50ml water samples were collected from each site to measure ammonium, nitrogen oxide, total nitrogen and total phosphorus concentrations. Samples were analysed following methods from the Standard Methods for the Examination of Water and Wastewater (A.P.H.A 2005).

Water quality guideline values for the Cotter, Googong and Goodradigbee catchments were based on the most conservative values from the Environment Protection Regulations SL2005-38 (which cover a variety of water uses and environmental values for each river reach in the ACT), and the ANZECC and ARMCANZ (2000) water quality guidelines for aquatic ecosystem protection in south-east Australian upland rivers. While comparisons with water quality guidelines are not required as part of the environmental flow guidelines, and are used only as a guide, they provide a useful tool for the protection of ecosystems (which is a primary objective of environmental flows). Only the upper guideline value for conductivity was used because concentrations below the minimum guideline level are unlikely to impact on the ecological condition of streams.

Table 2: Water quality guideline values from the Environment Protection Regulations SL2005-38* and ANZECC and ARMCANZ (2000)**. N/A *= guideline value not available*.

Measure	Units	Guideline value
Alkalinity	mg L^{-1}	N/A
Temperature	ºC	N/A
Conductivity**	µS cm^{-1}	<350
pH**	N/A	6.5-8
Dissolved oxygen *	mg L^{-1}	>6
Turbidity*	NTU	<10
Ammonium (NH_4^+)**	mg L^{-1}	<0.13
Nitrogen oxides**	mg L^{-1}	<0.015
Total phosphorus**	mg L^{-1}	<0.02
Total nitrogen**	mg L^{-1}	<0.25

PERIPHYTON AND FILAMENTOUS ALGAE

VISUAL OBSERVATIONS

Periphyton and filamentous algae visual observations within riffle habitats were recorded following methods outlined in the ACT AUSRIVAS sampling and processing manual (Nichols *et al.* 2000, http://ausrivas.ewater.com.au/ausrivas/index.php/manuals-a-datasheets?id=54).

ASH-FREE DRY MASS AND CHLOROPHYLL-A

Twelve replicate periphyton samples were collected at each of the Cotter and Goodradigbee River sites and site QM2 on the Queanbeyan River using a syringe sampler based on a design similar to that described by Loeb (1981). Samples from each site were measured for Ash-free dry mass (AFDM) and chlorophyll-a content in accordance with methods described in A.P.H.A (2005).

MACROINVERTEBRATE SAMPLE COLLECTION AND PROCESSING

Benthic macroinvertebrates were sampled from the riffle habitat following National River Health Program protocols presented in the ACT AUSRIVAS sampling and processing manual (Nichols *et al.* 2000; http://ausrivas.ewater.com.au/ausrivas/index.php/manuals-a-datasheets?id=54).

In the laboratory, preserved samples were placed in a sub-sampling box comprising of 100 cells (Marchant 1989) and agitated until evenly distributed. Contents of each cell were removed until approximately 200 animals from each sample were identified (Parsons and Norris 1996). Macroinvertebrates were identified to the family taxonomic level using keys listed by Hawking

(2000), except Chironomidae, which were identified to sub-family, aquatic worms (Oligochaeta) and mites (Acarina), which were identified to class. After the ~200 macroinvertebrates were sub-sampled, the remaining unsorted sample was visually scanned to identify taxa which were not found in the ~200 animal sub-sample (Nichols *et al*. 2000). QA/QC procedures were implemented for macroinvertebrate sample processing following those outlined in Nichols *et al*. (2000).

AUSRIVAS (AUSTRALIAN RIVER ASSESSMENT SYSTEM)

AUSRIVAS predicts the macroinvertebrate fauna expected to occur at a site with specific environmental characteristics, in the absence of environmental stress. The fauna observed (O) at a site can then be compared to fauna expected (E), with the deviation between the two providing an indication of biological condition (Coysh *et al*. 2000; http://ausrivas.ewater.com.au). A site displaying no biological impairment should have an O/E ratio close to one. The O/E ratio will decrease as the macroinvertebrate assemblage and richness are adversely affected.

The AUSRIVAS predictive model used to assess the biological condition of sites was the ACT autumn riffle model. The AUSRIVAS software and Users Manual (Coysh *et al.* 2000) is available online at: http://ausrivas.ewater.com.au . The ACT autumn riffle model uses a set of 12 habitat variables to predict the macroinvertebrate fauna expected to occur at each site in the absence of disturbance.

AUSRIVAS allocates test site O/E taxa scores to category bands that represent a range in biological conditions to aid interpretation. AUSRIVAS uses five bands, designated X, A, B, C, and D (Table 3). The derivation of model bandwidths is based on the distribution of O/E scores of the reference sites used to create each AUSRIVAS model (Coysh *et al.* 2000, http://ausrivas.ewater.com.au).

SIGNAL 2 GRADES

Habitat disturbance and pollution sensitivity grades (SIGNAL 2) range from 1 to 10, with sensitive taxa receiving higher grades than tolerant taxa. The sensitivity grades are based on taxa tolerance to common pollution types (Chessman 2003).

DATA ENTRY AND STORAGE

Water quality, habitat, and macroinvertebrate data were entered into an Open Office database. The layout of the database matches the field data sheets to minimise transcription errors. All data were checked for transcription errors using standard two person checking procedures. A backup of files was carried out daily.

DATA ANALYSIS

To determine if there were significant differences in periphyton AFDM and chlorophyll-a between sites in autumn 2016, single factor Analysis of Variance (ANOVA) (SAS 9.3) was used followed by Tukey-Kramer multiple comparisons. A $\log_{10}(x+1)$ transformation was applied to AFDM and chlorophyll-a data, before undertaking the ANOVAs, to ensure the data met the ANOVA assumptions.

Similarity in macroinvertebrate community structure between sites in terms of relative abundance data was assessed using the Bray-Curtis similarity measure and group average cluster analysis In PRIMER 6 (Clark and Warwick 2001). Groups in the cluster analysis were defined at 65% similarity. All data was fourth root transformed before the analysis to down weight the influence of highly abundant taxa.

Table 3: ACT autumn and spring riffle AUSRIVAS model band descriptions, band width and interpretation.

Band	Band description	Band width	Interpretation
X	MORE BIOLOGICALLY DIVERSE THAN REFERENCE	**>1.12** (autumn) **>1.14** (spring)	More taxa found than expected. Potential biodiversity hot-spot. Possible mild organic enrichment.
A	SIMILAR TO REFERENCE	**0.88-1.12** (autumn) **0.86-1.14** (spring)	Water quality and/or habitat condition roughly equivalent to reference sites.
B	SIGNIFICANTLY IMPAIRED	**0.64-0.87** (autumn) **0.57-0.85** (spring)	Potential impact either on water quality or habitat quality or both, resulting in loss of taxa.
C	SEVERELY IMPAIRED	**0.40-0.63** (autumn) **0.28-0.56** (spring)	Loss of macroinvertebrate biodiversity due to substantial impacts on water and/or habitat quality.
D	EXTREMELY IMPAIRED	**0-0.39** (autumn) **0-0.27** (spring)	Extremely poor water and/or habitat quality. Highly degraded.

RESULTS

HYDROMETRIC DATA

Stream discharge in the months leading up to autumn 2016 sampling at below dam sites on the Cotter and Queanbeyan Rivers was largely determined by operational requirements and environmental flow guidelines (ACT Government 2013) (Table 4).

Mean daily discharge at each of the below dam test sites and in the Goodradigbee River between November 2015 and the autumn 2016 sampling was generally similar (±10%) to that preceding the autumn 2015 assessment (Figure 2; Levings & Harrison 2015). The exceptions were at site QM2 downstream of Googong Reservoir, QM1 upstream of Googong Reservoir and CM3 downstream of Cotter Dam where the total discharge was approximately 3.05 times less, 1.35 times less and 0.3 times more than the same period preceding autumn 2015, respectively.

Table 4: Flow regime targets and releases downstream of Corin, Bendora, Cotter and Googong Dams (ACT Government 2013).

Dam	Flow regime
Corin	Maintain 75% of the 80^{th} percentile of the monthly natural inflow, or inflow, whichever is less. Riffle maintenance flow 150 ML d^{-1} for 3 consecutive days every 2 months. Maintain a flow of >550 ML d^{-1} for 2 consecutive days between mid-July and mid-October.
Bendora	Maintain 75% of the 80^{th} percentile of the monthly natural inflow, or inflow, whichever is less. Riffle maintenance flow 150 ML d^{-1} for 3 consecutive days every 2 months. Maintain a flow of >550 ML d^{-1} for 2 consecutive days between mid-July and mid-October.
Cotter	From Murrumbidgee to Cotter (M2C) transfer: If Murrumbidgee River flow at Mt MacDonald gauging station is greater than 80 MLd^{-1}, then M2C discharges 40 MLd^{-1}. Each month, M2C discharge flow is reduced temporarily to 20 ML d^{-1} for a 36 to 46 hour period. Cotter Dam releases bimonthly flows peaking at 100 MLd^{-1} and a flow peaking at 150 ML d^{-1} between mid-July and mid-October.
Googong	Maintain base flow average of 10 ML d^{-1} or natural inflow, whichever is less. Riffle maintenance flow of 100 ML d^{-1} for 1 day every 2 months.

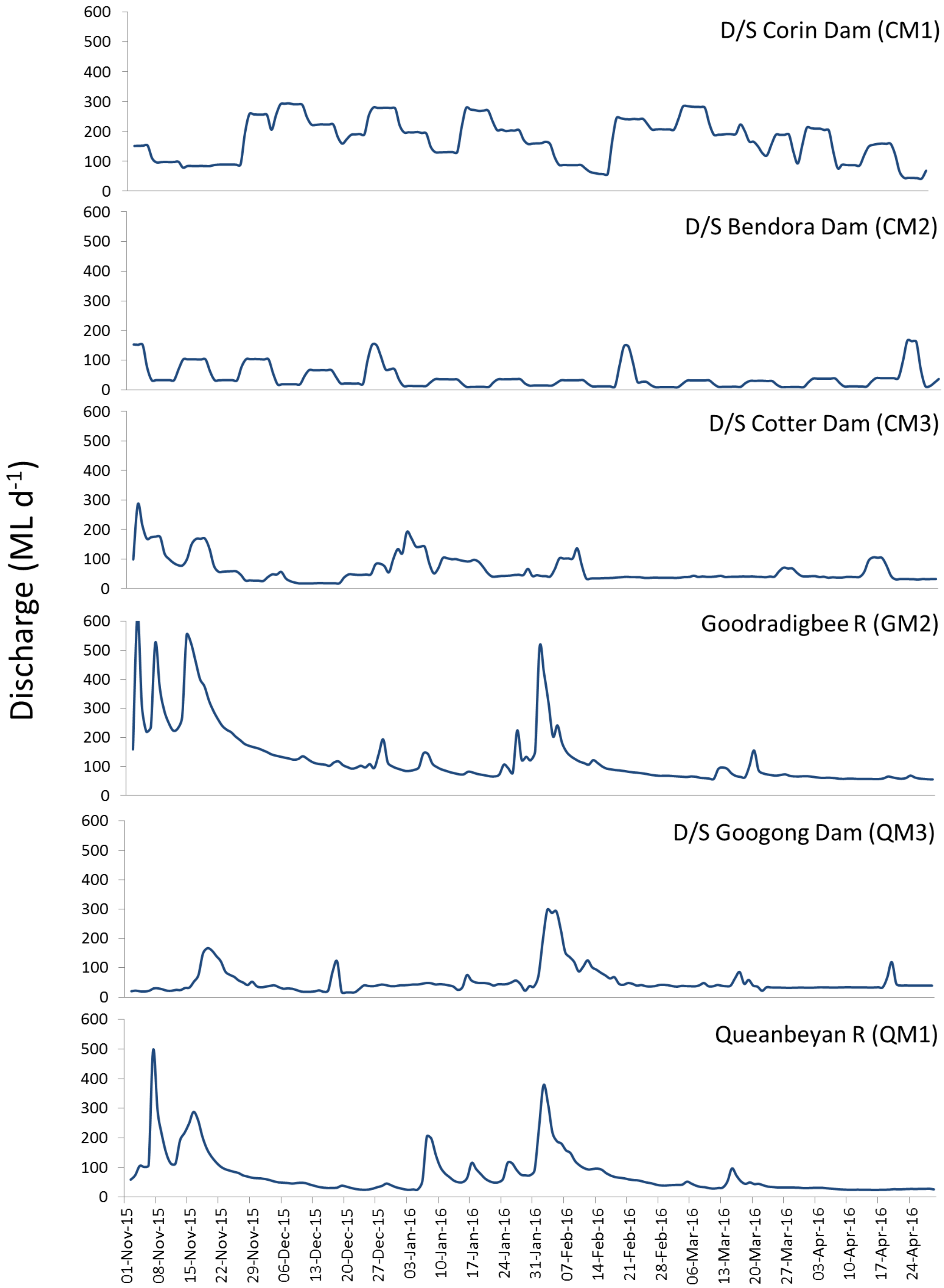

Figure 2. Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), and Cotter (CM3, station 410700) Dams and in the Goodradigbee River (GM2, station 410088) and Googong Dam (QM3, station 410760) and the Queanbeyan River upstream of Googong Reservoir (QM1, station 410781) from 1st November 2015 to 30th April 2016. Arrows correspond to autumn 2016 sampling dates.

WATER QUALITY

Water quality parameters were generally within guideline levels at test and reference sites in autumn 2016. Exceptions were pH at reference sites CT2, QM1, GM1, GM2, GT1, GT2, GT3; DO at reference site CT2; nitrogen oxides at test sites CM2, CM3, QM2, and QM3 and at reference sites CT2, GT2 and GT3; total nitrogen at test sites QM2 and QM3 (Table 5).

Table 5. Water quality parameters measured at each of the test and reference sites in autumn 2016. Values outside guideline levels are shaded orange.

		Temp. (°C)	EC (µs cm^{-1})	pH	DO (mg L^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3 N (mg L^{-1})	NO_x (mg L^{-1})	Total Nitrogen (mg L^{-1})	Total phosphorus (mg L^{-1})
		Guideline level									
		NA	350	6.5-8	>6	<10	NA	<0.13	<0.015	<0.25	<0.02
Below dam test sites	CM1	15.06	24	6.80	9.19	0.0	7	0.011	0.013	0.12	0.005
	CM2	13.66	25	6.58	9.62	3.4	7	0.017	0.054	0.15	0.005
	CM3	19	44	6.99	9.04	0.6	17	0.011	0.021	0.15	0.008
	QM2	19.08	91	7.71	9.64	0.0	35	0.016	0.047	0.37	0.009
	QM3	18.61	94	7.84	9.68	1.0	30	0.014	0.020	0.29	0.008
Reference sites	CT1	10.55	50	7.38	9.86	0.0	16	0.004	<0.002	<0.05	0.011
	CT2	15.32	44	5.72	4.86	0.0	12	0.008	0.057	0.10	<0.002
	CT3	18.2	87	7.57	9.58	7.7	32	0.004	0.003	0.17	0.012
	QM1	15.69	72	8.04	9.24	1.0	24	0.014	0.004	0.17	0.008
	GM1	13.7	118	8.44	10.52	0.0	64	0.006	<0.002	<0.05	0.002
	GM2	13.08	120	8.27	10.05	0.4	50	0.009	0.002	<0.05	0.003
	GM3	13.5	121	7.77	9.86	0.1	53	<0.002	0.004	<0.05	0.003
	GT1	12.96	61	8.32	10.11	0.2	24	0.015	0.014	0.08	0.004
	GT2	12.02	85	8.18	10.35	0.0	34	0.015	0.054	0.06	0.004
	GT3	11.67	60	8.16	10.46	0.0	24	0.014	0.036	0.06	0.004

FILAMENTOUS ALGAE AND PERIPHYTON

The environmental flow ecological objective of <20% cover of filamentous algae in riffle habitats was achieved at all below dams test sites except QM1 in autumn 2016. Field observations of periphyton and cover of riffle habitats were ≤10% cover at all sites in autumn 2016, except sites CM1, CM3 and QM3 which had a 20, 20 and 15% cover of periphyton, respectively (Table 6; Figure 3). Field observations of filamentous algae cover of riffle habitats were ≤10% cover at all sites in autumn 2016, except site QM1, which had 25% cover (Table 6; Figure 3).

Mean ash free dry mass (AFDM) was significantly greater below Cotter Dam (CM3) than below Googong Dam (QM2) ($F_{6,35}$=3.072; P = 0.016). Differences in AFDM between all other sites were not statistically significant (Figure 4).

Mean chlorophyll-a concentrations was significantly greater below Cotter Dam (CM3) than below Googong Dam (QM2) and Goodradigbee reference site GM1 ($F_{6,35}$ = 2.871 P = 0.022). Differences in chlorophyll-a concentrations between all other sites were not statistically significant (Figure 5).

Table 6: Periphyton and filamentous algae (categorised on percent cover) in the riffle habitat at below dams sites and reference sites, from spring 2013 to autumn 2016. Filamentous algae observations greater than the environmental flow ecological objective of <20% cover are shaded orange.

% cover of riffle habitat													
	Periphyton							Filamentous algae					
	Spr-13	Aut-14	Spr-14	Aut-15	Spr-15	Aut-16		Spr-13	Aut-14	Spr-14	Aut-15	Spr-15	Aut-16
CM1	10	<10	10	20	20	20		80	<10	25	10	20	10
CM2	20	<10	<10	<10	<10	<10		20	<10	10	<10	<10	<10
CM3	50	<10	75	20	25	20		<10	<10	10	<10	15	<10
QM3	20	10	10	<10	10	15		<10	<10	10	<10	10	<10
GM1	20	10	10	<10	<10	<10		<10	<10	10	<10	<10	<10
GM2	<10	<10	<10	<10	<10	<10		<10	<10	<10	0	<10	<10
GM3	<10	<10	<10	<10	10	10		<10	<10	<10	<10	10	10
QM1	10	<10	<10	10	40	<10		15	<10	<10	10	40	25
QM2	<10	<10	10	10	<10	10		<10	<10	10	10	<10	10

Figure 3. Filamentous algae cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in autumn 2016.

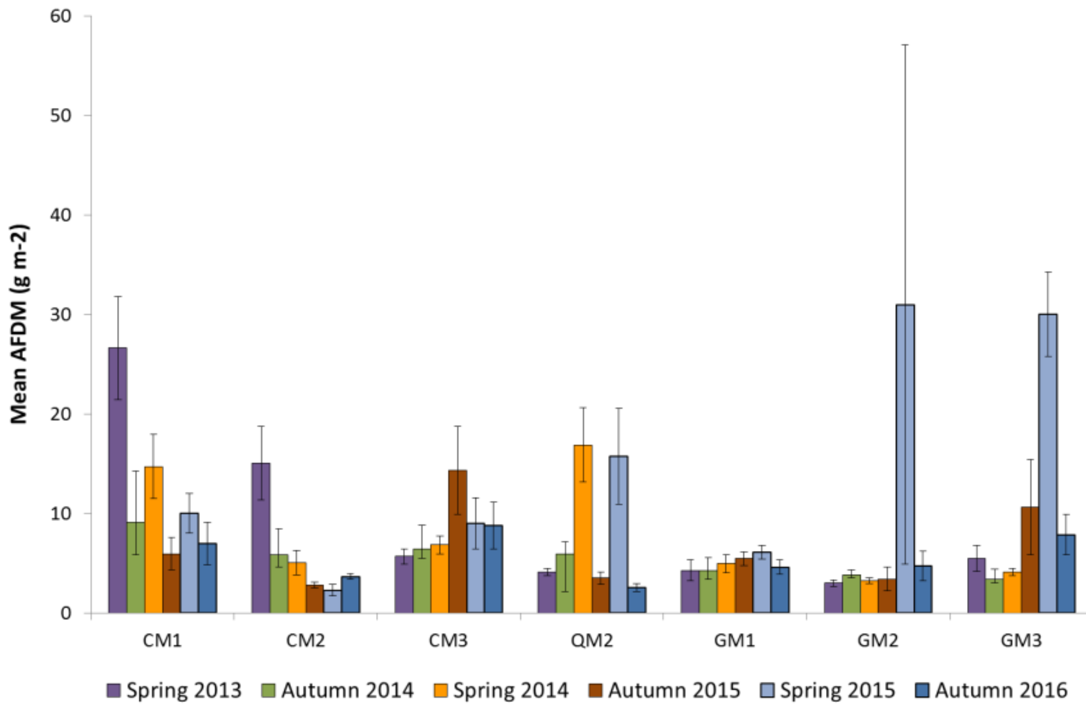

Figure 4: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2013 to autumn 2016. Error bars represent +/- 1 standard error.

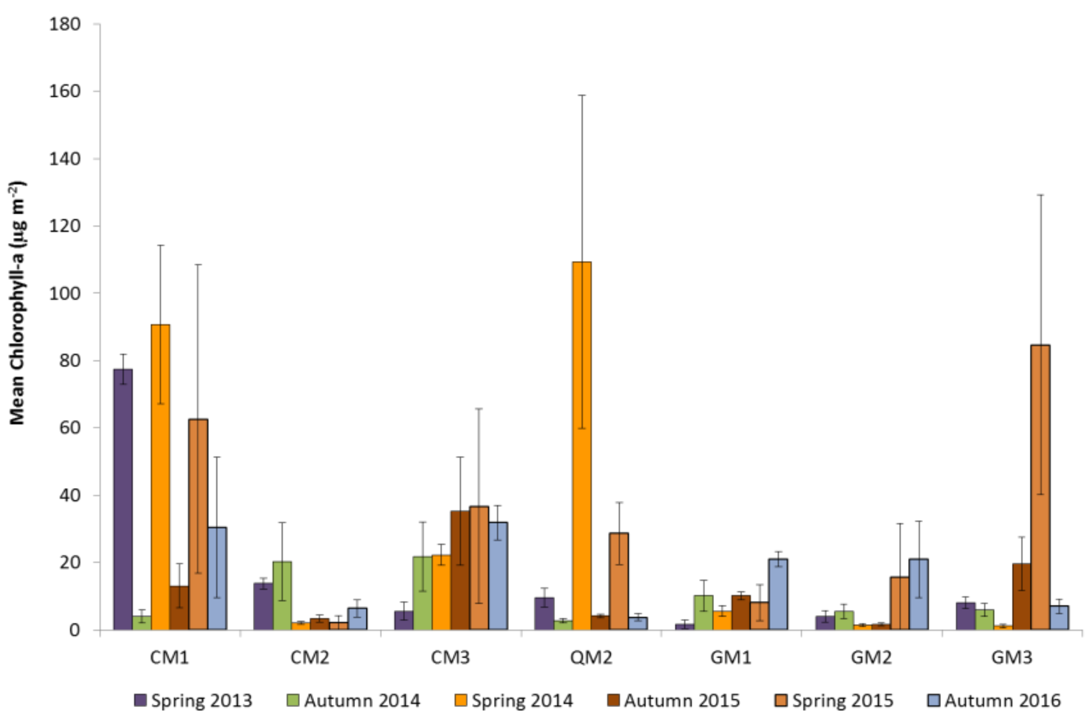

Figure 5: Mean chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2013 to autumn 2016. Error bars represent +/- 1 standard error.

BENTHIC MACROINVERTEBRATES

AUSRIVAS ASSESSMENT

Below dam test sites were generally in poorer biological condition than reference sites on the Goodradigbee and Queanbeyan Rivers based on AUSRIVAS assessment in autumn 2016 (Table 7).

Cotter River test site CM1 was assessed as significantly impaired (band B), and test sites CM2 and CM3 were similar to reference condition (band A) in autumn 2016. Cotter River Test site CM3 increased in condition from B to A since spring 2015 (Table 7).

Goodradigbee River reference sites GM1 and GM3 were assessed as biologically impaired (band B), both having largely being similar to reference for the past 3 years (Table 7). Goodradgibee River site GM2 has remained in reference condition since autumn 2012 (Table 7).

Cotter River tributary site CT2 was not able to be sampled as the creek had dried up into a series of very small pools (< 1 m in length). The other two Cotter River tributary sites (CT1 and CT3) were assessed as more diverse than reference condition (band X) and similar to reference condition (band A), respectively. Goodradigbee River tributary sites GT1, GT2 and GT3 were assessed as similar to reference condition (Table 7).

Queanbeyan River test sites QM2 and QM3 downstream of Googong Dam were assessed as significantly impaired (band B) in autumn 2016. Site QM3 has been variable in condition over the past three assessments ranging from severely impaired (band C) in autumn 2015 to similar to reference condition (band A) in spring 2015 (Table 7). This variation in biological condition was not evident at the upstream reference site on the Queanbeyan River (site QM1) which was assessed as similar to reference condition (band A) (Table 7). This Queanbeyan River reference site has not been assessed as biologically impaired since autumn 2009 (White et al 2009).

Taxa expected with a ≥50% chance of occurrence by the AUSRIVAS model, but missing from sub-samples are presented in Table 8. Missing taxa ranged in SIGNAL 2 grade from 2 (Oligochaeta) to 9 (Glossosomatidae). Cotter River and tributary sites CM2, CM3 and CT3; Queanbeyan River site QM1; and Goodradigbee River and tributary sites GM2, GM3, GT1, GT2 and GT3 had taxa identified in whole of sample scans that were missing from respective sub-samples. This indicates these taxa (Hydrobiosidae – sites CM2, CM3, GM2 and GM3; Psephenidae – sites CM2, CM3, QM1 and GT1; Gomphidae – sites CM3, CT3, GM3 and GT3; and Oligochaeta – site GT2) were present, but in low abundance (Table 8).

Table 7: AUSRIVAS band and Observed/Expected taxa score for each site from spring 2013 to autumn 2016.

	Below dams sites					Reference sites									
	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Autumn 2016	B (0.85)	A (0.94)	A (0.89)	B (0.84)	B (0.69)	X (1.16)	Not sampled	A (0.90)	A (1.04)	B (0.84)	A (0.97)	B (0.74)	A (1.12)	A (0.93)	A (0.97)
Spring 2015	B (0.69)	A (0.89)	B (0.66)	B (0.80)	A (1.07)	A (0.96)	X (1.15)	A (0.96)	A (1.1)	X (1.27)	A (1.04)	X (1.19)	X (0.91)	A (0.98)	A (1.21)
Autumn 2015	B (0.85)	A (0.94)	B (0.67)	C (0.49)	C (0.63)	A (0.93)	B (0.77)	B (0.70)	A (0.97)	B (0.81)	A (1.05)	A (1.12)	X (1.16)	A (1.05)	A (1.05)
Spring 2014	B (0.77)	A (0.97)	B (0.66)	A (0.88)	B (0.84)	A (1.03)	A (1.07)	A (0.96)	A (0.92)	A (1.12)	A (1.11)	A (1.12)	A (1.13)	A (0.98)	A (1.05)
Autumn 2014	A (0.91)	B (0.86)	B (0.66)	B (0.70)	B (0.83)	A (0.96)	A (0.90)	B (0.84)	A (0.97)	A (0.88)	A (1.04)	A (0.97)	X (1.19)	A (1.12)	A (1.05)
Spring 2013	B (0.69)	A (0.89)	A (0.88)	A (0.88)	A (0.92)	X (1.16)	A (1.00)	B (0.74)	A (1.10)	X (1.19)	A (1.11)	X (1.19)	A (1.13)	A (0.98)	A (1.13)

Table 8. Macroinvertebrate taxa that were expected with a ≥ 50% chance of occurrence by the AUSRIVAS ACT autumn riffle model but were missing from sub-samples for each of the study sites in autumn 2016 and their SIGNAL 2 grade (Chessman 2003). Orange shading indicates missing taxa that were identified in the whole of sample scan.

	SIGNAL 2 grade	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Hydrobiidae	4				X	X			X		X		X			
Ancylidae	4				X	X			X		X		X			
Oligochaeta	2					X									X	
Scirtidae	6	X													X	
Elmidae	7															
Psephenidae	6		X	X						X				X		X
Tipulidae	5														X	
Simuliidae	5															
Podonominae	6		X	X	X	X				X	X	X	X			X
Tanypodinae	4	X			X	X			X		X		X	X		
Orthocladiinae	4															
Chironominae	3															
Baetidae	5						X									
Coloburiscidae	8	X													X	
Leptophlebiidae	8			X		X										
Caenidae	4											X				
Gomphidae	5			X					X	X			X			X
Gripopterygidae	8								X							
Hydrobiosidae	8	X	X	X	X							X	X	X		
Glossosomatidae	9	X													X	
Hydroptilidae	4		X			X					X	X	X			X
Hydropsychidae	6															
Conoesucidae	7															
Leptoceridae	6	X	X		X	X			X		X					
Total		**6**	**5**	**5**	**6**	**8**	**1**	**n/a**	**6**	**3**	**6**	**4**	**7**	**3**	**5**	**4**

TAXONOMIC RELATIVE ABUNDANCE

The ratio of environmentally tolerant Oligochaeta and Chironomidae (OC) taxa to more sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa was variable across all sites (Figure 6). Tolerant OC taxa were more prevalent at below dam test sites on the Cotter River, than at reference sites, especially at site CM3 below Cotter Dam which was the only site where OC taxa outnumbered EPT taxa (largely due to large numbers of Orthocladiinae) (Appendix 2 and Figure

6). Filter feeding Simuliidae comprised 50% of the sub-sample at Cotter River test site CM2 (Appendix 2).

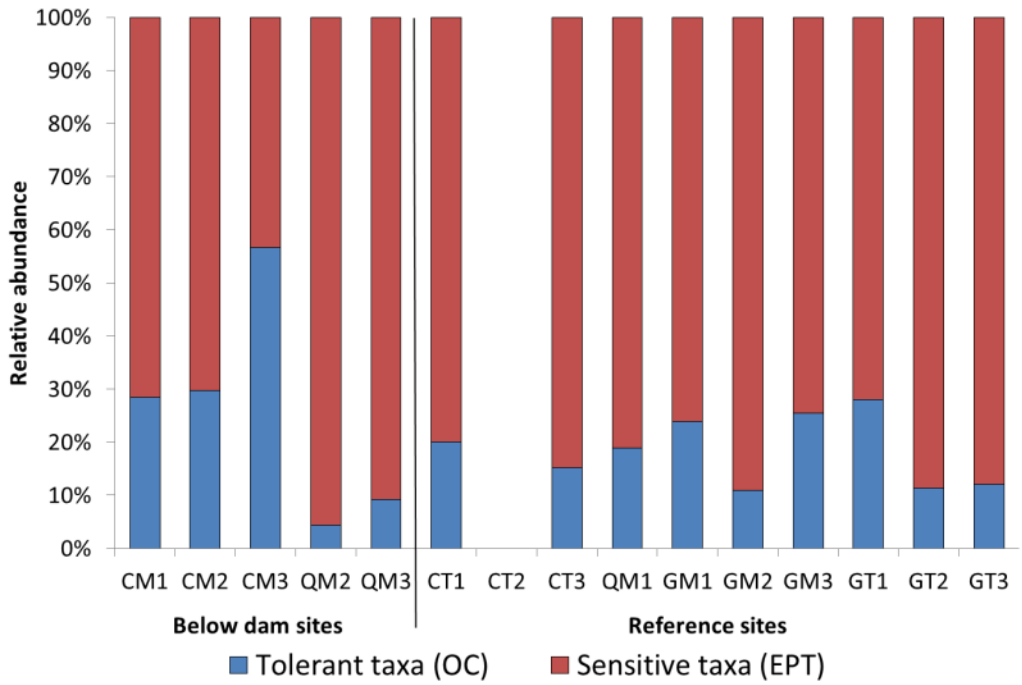

Figure 6. Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in autumn 2016. Note: CT2 not sampled due to lack of riffles.

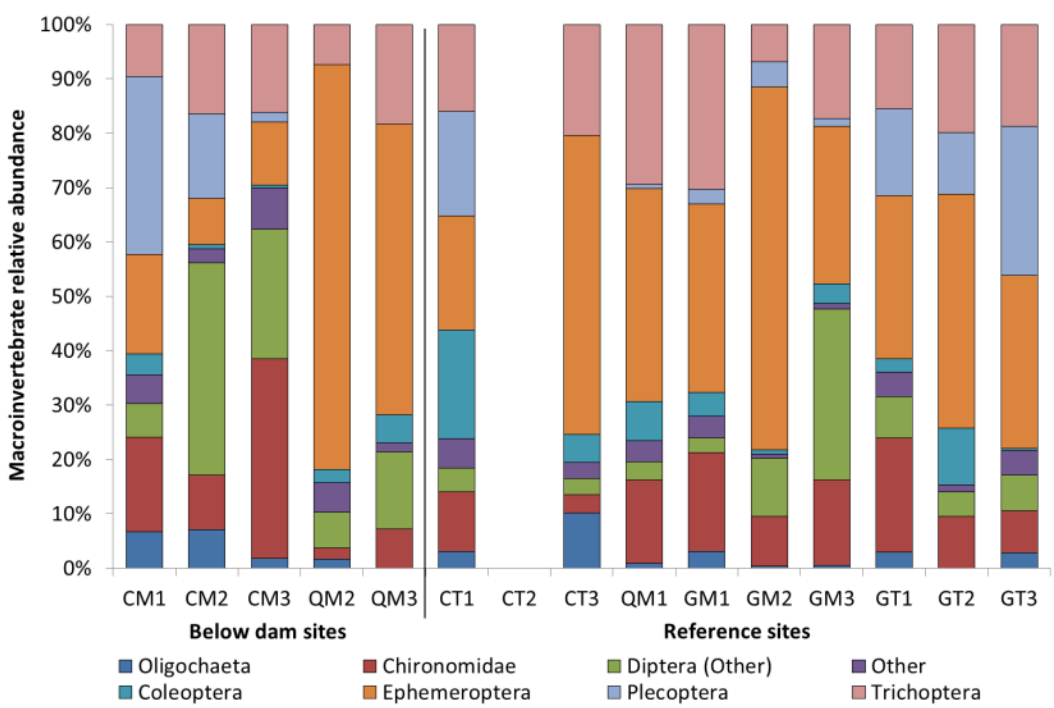

Figure 7: Relative abundance of macroinvertebrate taxonomic groups from samples collected in autumn 2016. Note: CT2 not sampled due to lack of riffles.

MACROINVERTEBRATE ASSEMBLAGE SIMILARITY

Cluster analysis based on the relative abundance of macroinvertebrate taxa identified six groups of sites at 65% similarity (Figure 8). Cotter River test site CM3 (Below Cotter Dam), Goodradgibee River site GM2 and Cotter Tributary site CT1 (Kangaroo Creek) had macroinvertebrate assemblages dissimilar to all other sites. Cotter River test site CM3 (Below Cotter Dam) had a higher relative abundance of Simuliidae, a particulate filter feeder. The macroinvertebrate assemblage at test sites QM2 and QM3 (both below Googong Dam) grouped out together (Figure 8). Cotter River test sites CM1 and CM2 grouped out with reference sites GM1 and GM3, and tributary sites GT2 and GT3 (Figure 8). Cotter Tributary site CT1 and Goodradigbee tributary site CT3 grouped together with the Queanbeyan River reference site QM1 (Figure 8).

Queanbeyan River test sites QM2 and QM3 had macroinvertebrate assemblages that were dissimilar to all other sites. This was primarily because of the higher relative abundance of more environmentally tolerant Caenidae at these sites compared to sites which had greater relative abundances of Podonominae and environmentally sensitive taxa Gripopterygidae, Polcentrapodidae and Ptilodactylidae (Figure 8; Appendix 2).

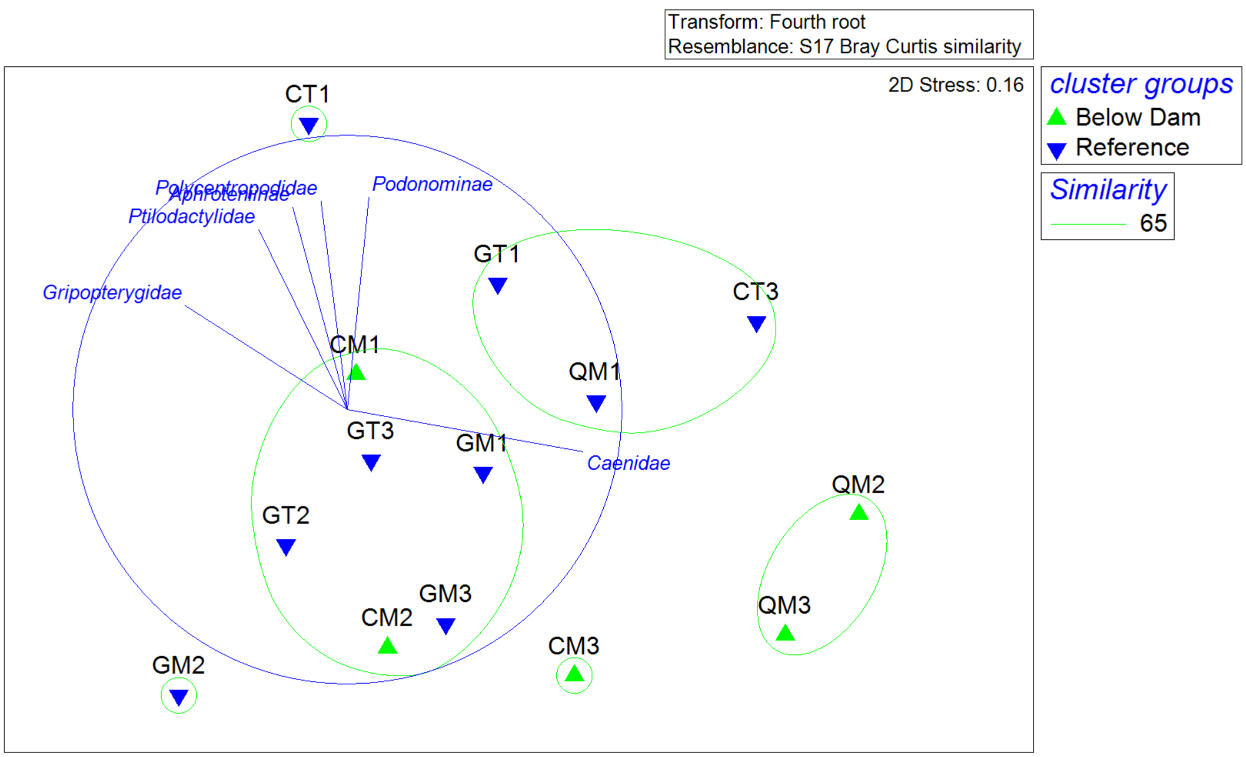

Figure 8. MDS ordination of 65% similarity between macroinvertebrate samples collected in autumn 2016 for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.7 (i.e. taxa that discriminate between the groups of sites) are overlayed on the MDS ordination. The closer the blue line for each taxa is to the edge of the blue circle the greater the correlation.

DISCUSSION

WATER QUALITY

Water quality at below dam test sites and unregulated reference sites was generally within guideline levels in autumn 2016 (Table 5). Parameters outside of guideline levels were pH, Dissolved Oxygen, nitrogen oxides (NO_x) and total nitrogen (TN) (Table 5).

pH was within guideline levels of 6.5-8 at all below dam test sites, though exceeded the guideline levels at all of the reference sites except Cotter tributary sites CT1 and CT3, and Goodradigbee River site GM3 (Table 5).

Nitrogen oxides (NOx) and total nitrogen (TN) were well above guideline concentrations downstream of Googong Dam (site QM2 and QM3) and downstream of Bendora Dam (site CM2) and Cotter Dam (CM3) in autumn 2016 (Table 5). NOx concentrations at the test sites downstream of Googong were approximately ten times those of inflows to Googong Reservoir from the Queanbeyan River upstream (reference site QM1), while TN concentrations were approximately double those of inflows (from site QM1). This is likely to be a result of high TN concentrations present in Googong Reservoir which are likely sourced from the reservoir (release from sediments or from the breakdown of vegetative matter Nowlin et al. 2005) or from the upstream Queanbeyan River during high flow events (during which loads of Nitrogen can be transported into the reservoir), and denitrification within the reservoir causing elevated NOx concentrations in outflows (Saunders and Kalff 2001). Therefore, while elevated NOx concentrations are likely to be attributable to the presence of the reservoir, neither the high NOx or TN concentrations in outflows can be attributed to the operation or management of Googong Reservoir.

FILAMENTOUS ALGAE AND PERIPHYTON

Filamentous algae cover in riffle habitats was well below the environmental flow ecological objective of <20% cover at all sites except the Queanbeyan River reference site (QM1) in autumn 2016 (Table 6). This is somewhat consistent with recent autumn assessments, and indicates that the current environmental flow release strategy is effective in achieving the environmental flow ecological objective to control filamentous algae accumulation downstream of dams on the Cotter and Queanbeyan Rivers during autumn.

Periphyton/algae biomass was the highest of all sites at the riffle habitat downstream of Cotter Dam, though was only significantly greater than the site immediately downstream of Googong Dam – QM2 in autumn 2016 (Figure 4). Periphyton/algae biomass across all sites was within the range of those measured in recent sampling (dating back to spring 2013).

BENTHIC MACROINVERTEBRATES

AUSRIVAS assessment identified biological impairment at three of the five below dam test sites in autumn 2016, which is a net decline in condition at below dam test sites since the previous assessment in spring 2015, but is slightly better than other autumn assessments over recent years (Table 7).

The Cotter River test site below Corin (CM1) remained significantly impaired and therefore failed to meet the environmental flow ecological objective of AUSRIVAS band A. This was despite having a reasonably high taxonomic richness (Appendix 2) and high percentage of environmentally sensitive taxa in autumn 2016 (Figure 6). The diverse and environmentally sensitive macroinvertebrate community at this site indicates that biological impairment is only minor downstream of Corin Dam, as reflected by the AUSRIVAS assessment on the upper limit of AUSRIVAS band B (Table 7).

Cotter River test sites CM2 (downstream of Bendora Dam) and CM3 (downstream of Cotter Dam) were the only test sites to achieve the environmental flow ecological objective of AUSRIVAS band A in autumn 2016 (Table 7). Despite the relatively low flows at both of these sites in the six months prior to sampling, the macroinvertebrate assemblages at these sites were in fact similar or in better biological condition to that of the three reference sites on the Goodradigbee River (Figure 8).

Sites GM1 and GM3 on the Goodradigbee River were assessed as significantly impaired (band B) in autumn 2016 (Table 7). These sites are generally in reference condition (apart from GM1 which was band B in autumn 2015), and in the absence of apparent stressors it is likely that this outcome was a result of natural variation. Site GM1 and GM3 had similar macroinvertebrate community assemblages to the tributary sites GT2, GT3, and the Cotter River test site CM2, all of which were assessed as band A.

The two Cotter River tributary sites that were able to be assessed were similar to reference condition (band A CT3) or more diverse than reference condition (band X CT1) in autumn 2016 (Table 7). Site CT3 on Paddys River is influenced by land-use effects and has resulted in variable biological condition results over the past eight years. Site CT1 is wholly within Namadgi National Park and is not susceptible to catchment use stressors, which is reflected by its generally similar to reference condition index.

Queanbeyan River test sites QM2 and QM3 below Googong Dam were both assessed as significantly impaired (band B) in autumn 2016 (Table 7), and the upstream reference site was similar to reference condition (band A). Macroinvertebrate sub-samples from these sites had ratios of sensitive EPT: tolerant OC taxa similar to reference sites; however it was a numerical dominance of more tolerant Ephermeroptera taxa Caenidae which comprised approximately 50% of the sample from each site.

CONCLUSION

Water quality parameters at below dam test sites were largely within guideline levels in autumn 2016, with the exception of nitrogen oxides (NO_x) and total nitrogen (TN) which were above guideline levels at four of the five sites and two of the five test sites, respectively. Despite this nutrient availability, filamentous algae coverage of riffle habitats remained well within environmental flow ecological objective levels at all test sites. Site CM2 (downstream of Bendora Dam) and CM3 (downstream of Cotter Dam) were the only test sites to achieve AUSRIVAS band A assessment.

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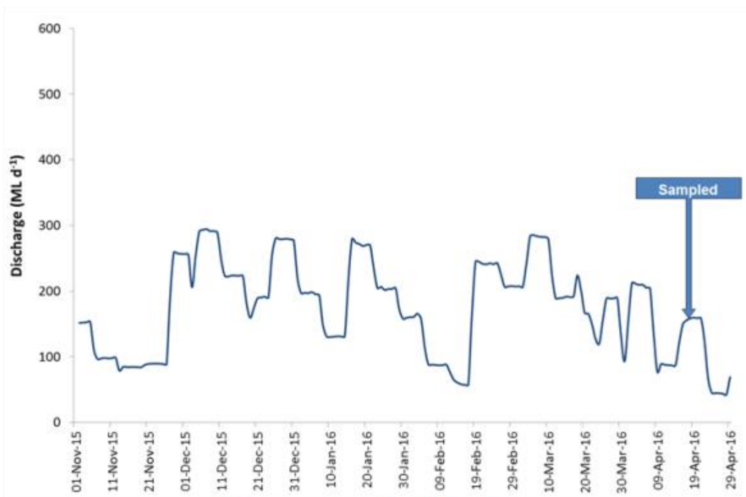
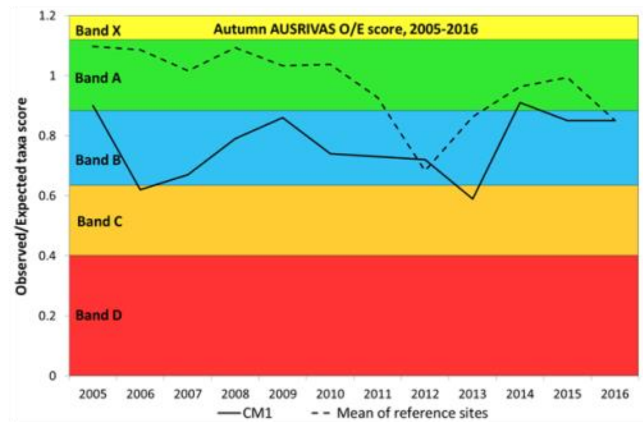
APPENDIX 1: BELOW DAM SITE SUMMARY SHEETS

CM1 – Autumn 2016

Downstream of Corin Dam

Environmental flow ecological objective	Spring 2015	Autumn 2016	Objective met?
AUSRIVAS band A	Band B	**Band B**	No
<20% filamentous algae cover in riffle habitat	20%	**10%**	Yes





* Denotes values outside guideline levels

Temp. (°C)	EC ($\mu s\ cm^{-1}$)	pH	D.O. ($mg\ l^{-1}$)	Turbidity (NTU)	Alkalinity ($mg\ L^{-1}$)	NH_4^+ ($mg\ L^{-1}$)	NOx ($mg\ L^{-1}$)	TN ($mg\ L^{-1}$)	TP ($mg\ L^{-1}$)
15.06	24	6.80	9.19	0.0	7	0.011	0.013	0.12	0.005

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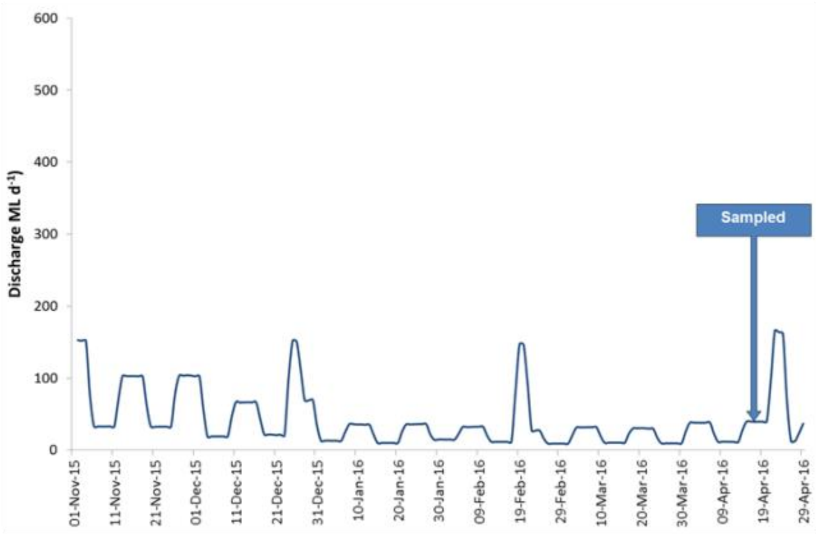
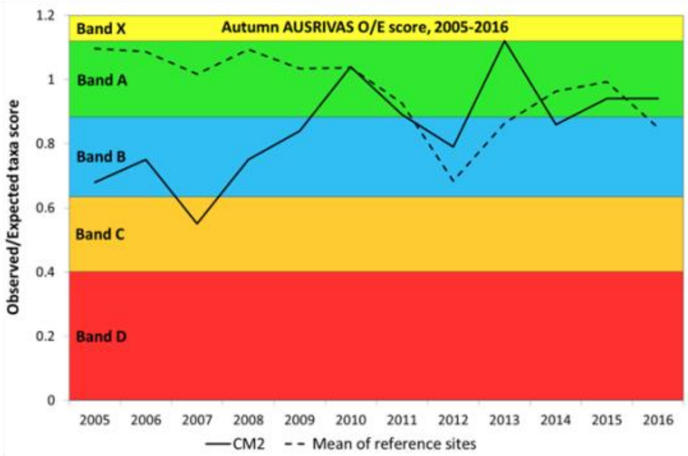
CM2 – Autumn 2016

Downstream of Bendora Dam

Environmental flow ecological objective	Spring 2015	Autumn 2016	Objective met?
AUSRIVAS band A	Band A	**Band A**	Yes
<20% filamentous algae cover in riffle habitat	<10%	**<10%**	Yes





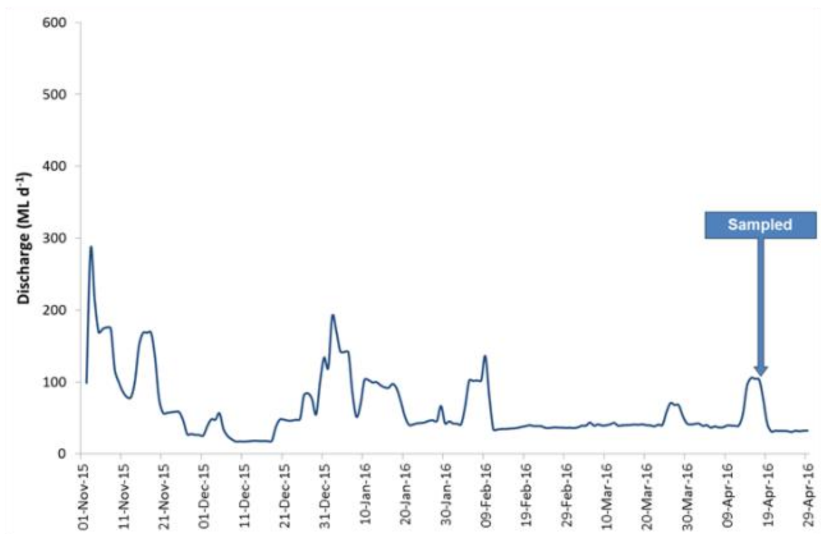
* Denotes values outside guideline levels

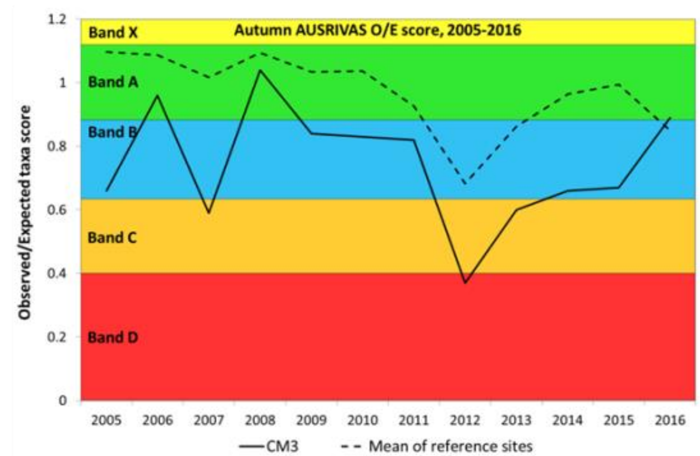
Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_4^+(mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
13.66	25	6.58	9.62	3.4	7	0.017	0.054	0.15	0.005

CM3 – Autumn 2016

Downstream of Cotter Dam

Environmental flow ecological objective	Spring 2015	Autumn 2016	Objective met?
AUSRIVAS band A	Band B	Band A	Yes
<20% filamentous algae cover in riffle habitat	15	<10%	Yes





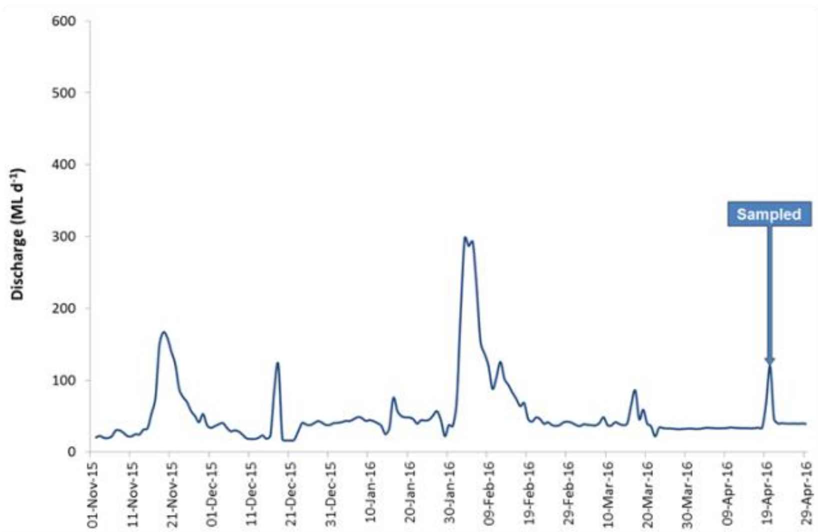
* Denotes values outside guideline levels

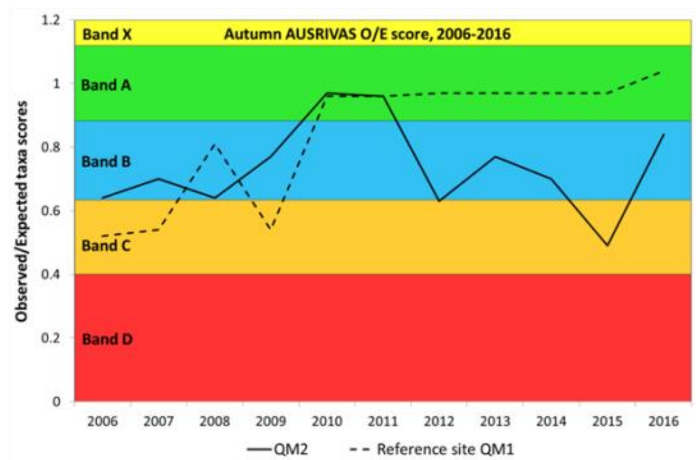
Temp. (°C)	EC (µs cm⁻¹)	pH	D.O. (mg l⁻¹)	Turbidity (NTU)	Alkalinity (mg L⁻¹)	NH_4^+(mg L⁻¹)	NOx (mg L⁻¹)	TN (mg L⁻¹)	TP (mg L⁻¹)
19	44	6.99	9.04	0.6	17	0.011	0.021	0.15	0.008

QM2 – Autumn 2016

Downstream of Googong Dam

Environmental flow ecological objective	Spring 2015	Autumn 2016	Objective met?
AUSRIVAS band A	Band B	**Band B**	No
<20% filamentous algae cover in riffle habitat	<10%	**10%**	Yes





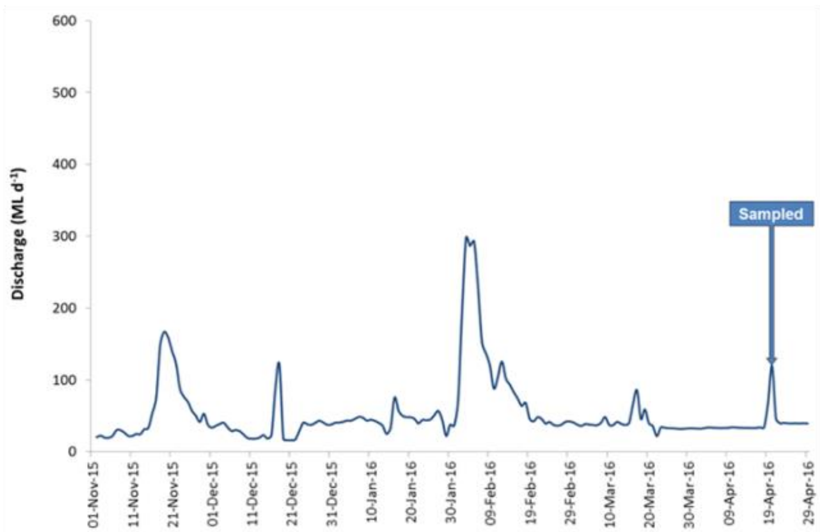
* Denotes values outside guideline levels

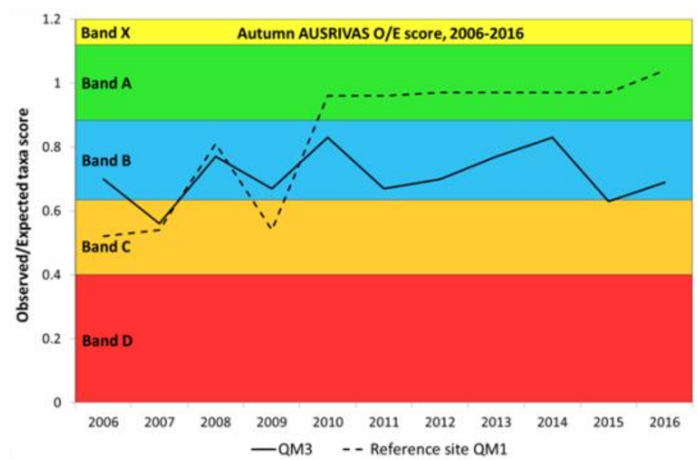
Temp. (°C)	EC (µs cm⁻¹)	pH	D.O. (mg l⁻¹)	Turbidity (NTU)	Alkalinity (mg L⁻¹)	NH_4^+ (mg L⁻¹)	NOx (mg L⁻¹)	TN (mg L⁻¹)	TP (mg L⁻¹)
19.08	91	7.71	9.64	0.0	35	0.016	**0.047**	**0.37**	0.009

QM3 – Autumn 2016

2km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2015	Autumn 2016	Objective met?
AUSRIVAS band A	Band A	Band B	No
<20% filamentous algae cover in riffle habitat	10%	<10%	Yes





* Denotes values outside guideline levels

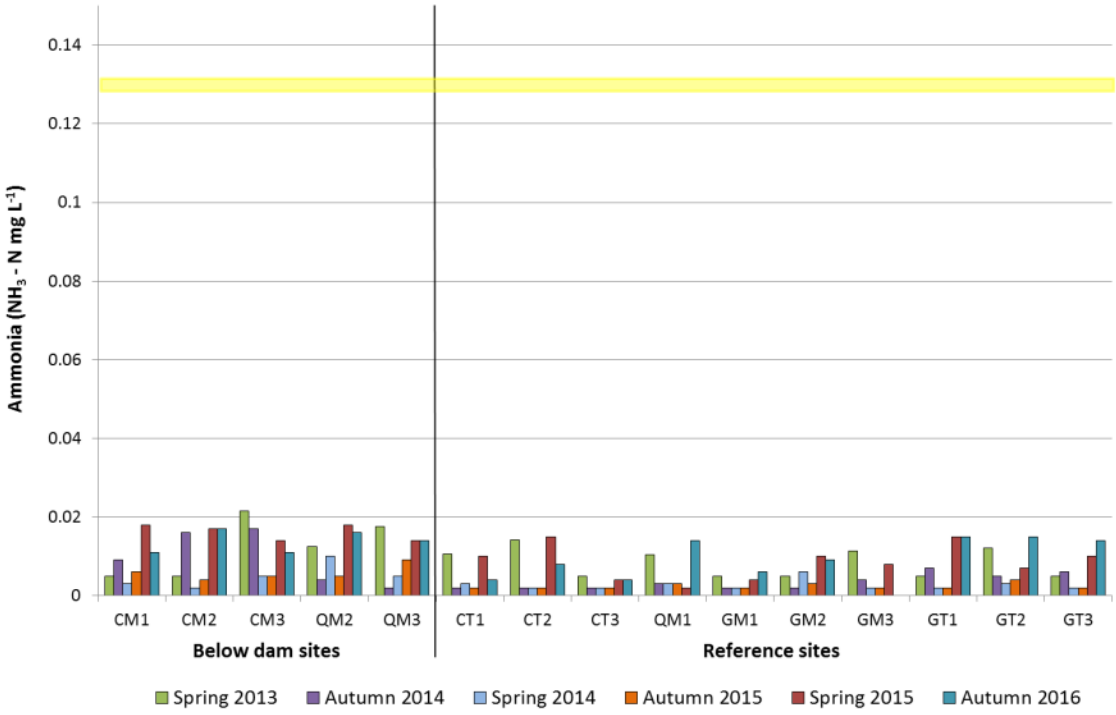
Temp. (°C)	EC (µs cm⁻¹)	pH	D.O. (mg l⁻¹)	Turbidity (NTU)	Alkalinity (mg L⁻¹)	NH_4^+ (mg L⁻¹)	NOx (mg L⁻¹)	TN (mg L⁻¹)	TP (mg L⁻¹)
18.61	94	7.84	9.68	1.0	30	0.014	0.020	0.29	0.008

APPENDIX 2: MACROINVERTEBRATE TAXA AUTUMN 2015

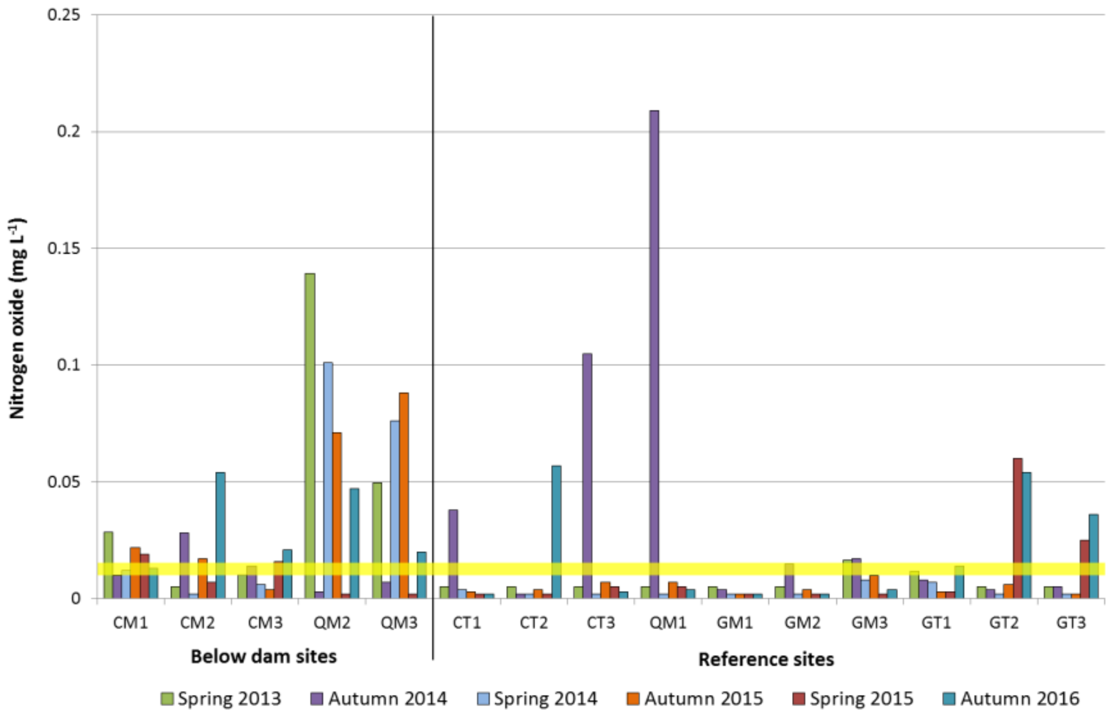
Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in autumn 2016 at each of the study sites.

CLASS **Order** Family *Subfamily*	**Signal 2 Grade**	**CM1**	**CM2**	**CM3**	**QM2**	**QM3**	**QM1**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**	**CT1**	**CT3**	**CT2**
TURBELLARIA	2				4											
MOLLUSCA					1											
Gastropoda																
Planorbidae	4	2	2	12						1						
PELECYCOPODA																
Sphaeriidae	5							1						5		
OLIGOCHAETA	2	14	19	4	4		2	8	1	1	6		7	8	24	
ACARINA	6	6	4	2	3	2	7	2	1	1	9	2	10	6	3	
Coleoptera																
Scirtidae	6				1											
Elmidae	7	5	2	1	5	12	17	5	1	7	5	14	1	43	12	
Psephenidae	6	1						6	1			9		3		
Ptilodactylidae	10	2												5		
Diptera																
Tipulidae	5	4	1		2	4	4	3		5	11		2		1	
Dixidae	7											3	11			
Ceratopogonidae	4					1					1		1		1	
Simuliidae	5	2	104	51	14	28	2	3	28	56	3	7	2	4	1	
Athericidae	8	7		2				1						4	1	
Empididae	5						2			1				3	3	
Aphroteniinae	8						1				1			3		
Podonominae	6										3			3	3	
Tanypodinae	4		5	2			1		1			3	5	1		
Orthocladiinae	4	34	13	67	3	13	31	21	2	25	26	13	10	9	3	
Chironominae	3	2	9	13	2	4	3	25	21	6	12	5	4	12	2	
Ephemeroptera																
Baetidae	5	6	9	5	72	11	11	32	8	46	8	3	16		50	
Coloburiscidae	8						2	5	7	2			1	25		
Leptophlebiidae	8	29	4		1		26	24	160	5	43	68	55	27	32	
Caenidae	4	3	10	21	107	114	53	27		4	9	24	6	2	48	
Hemiptera																
Hemiptera															1	
Megaloptera																
Corydalidae	7	3	1	2	3	1						1	1			
Odonata																
Gomphidae	5				2	1		7	1							
Telephlebiidae	9			1			1							3	3	
Plecoptera																
Austroperlidae	10										1					
Gripopterygidae	8	68	42	4			2	7	12	3	31	25	67	49		
Trichoptera																
Hydrobiosidae	8					1	2	2				7	2	1	1	
Hydroptilidae	4	2		2	1		21				4			2	1	
Philopotamidae	8			4		3	19	1	5	1		1		2	1	
Hydropsychidae	6	10	30	26	7	37	16	51	10	24	4	5	15	2	26	
Polycentropodidae	7			1		1	1	1			4			9	2	
Ecnomidae	4			2	10	1	10	5			6	6	5		10	
Conoesucidae	8	8	13	1				16	2	5	2	8	23	22		
Helicopsychidae	8													1		
Calocidae	9										5					
Philorheithridae	8													1		
Odontoceridae	7									1	2				7	
Calamoceratidae	7		1					1		2		5	1	1		
Leptoceridae	6								1	1	4	12				
No. of individuals		**208**	**269**	**223**	**242**	**234**	**234**	**254**	**262**	**197**	**200**	**221**	**245**	**256**	**236**	**0**
No. of taxa		**19**	**17**	**20**	**18**	**16**	**22**	**23**	**17**	**20**	**23**	**20**	**21**	**28**	**23**	**0**
% of sub-sample		**7**	**4**	**4**	**2**	**3**	**4**	**2**	**2**	**2**	**1**	**1**	**2**	**4**	**3**	**0**
Whole sample estimate		**2971.4**	**6725**	**5575**	**12100**	**7800**	**5850**	**12700**	**13100**	**9850**	**20000**	**22100**	**12250**	**6400**	**7866.7**	**0**

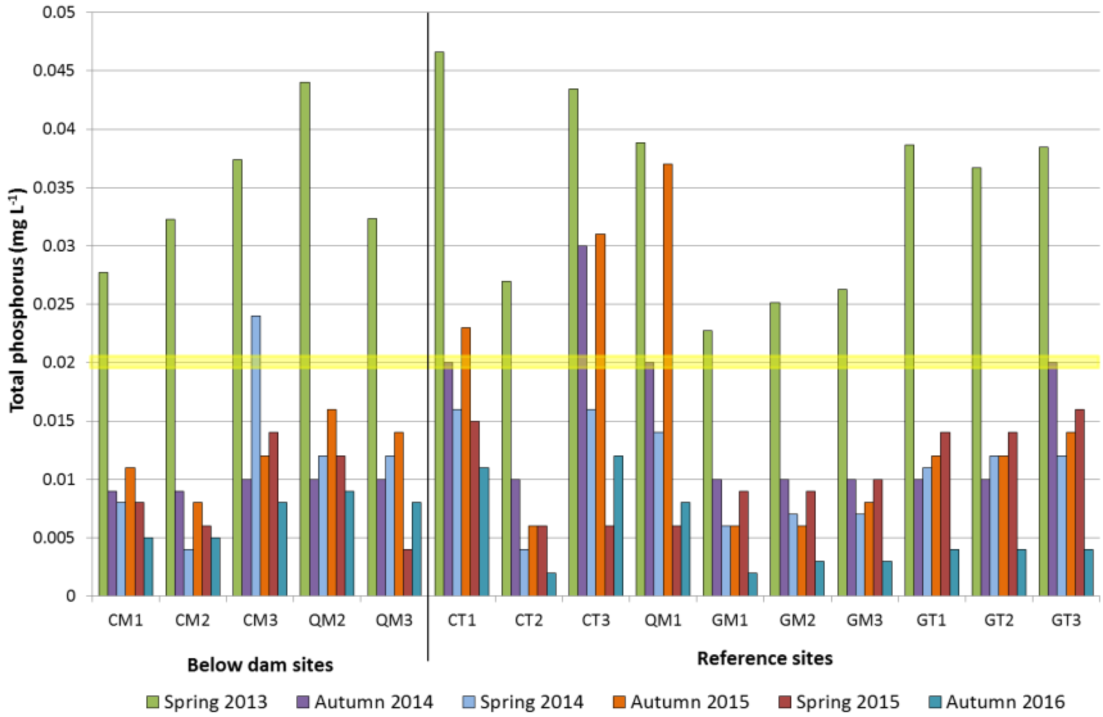
APPENDIX 3: WATER QUALITY FIGURES



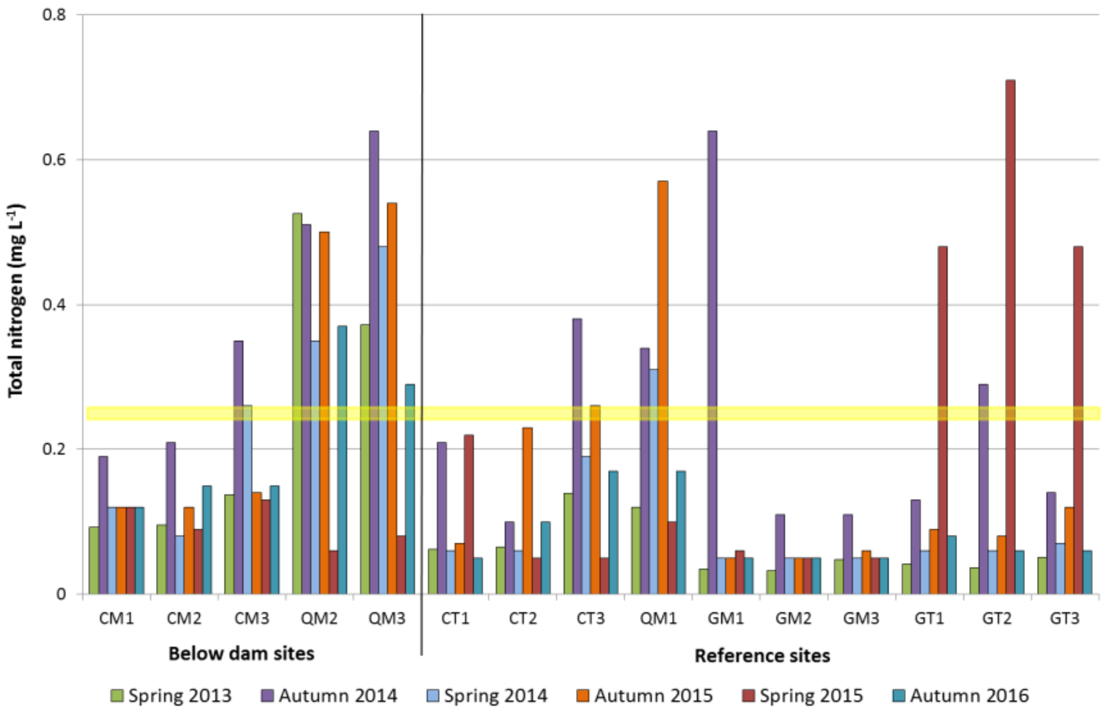
Ammonium (NH_4^+) concentration at all sites from spring 2013 to autumn 2016. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for ammonium (NH_4^+) is shaded yellow.



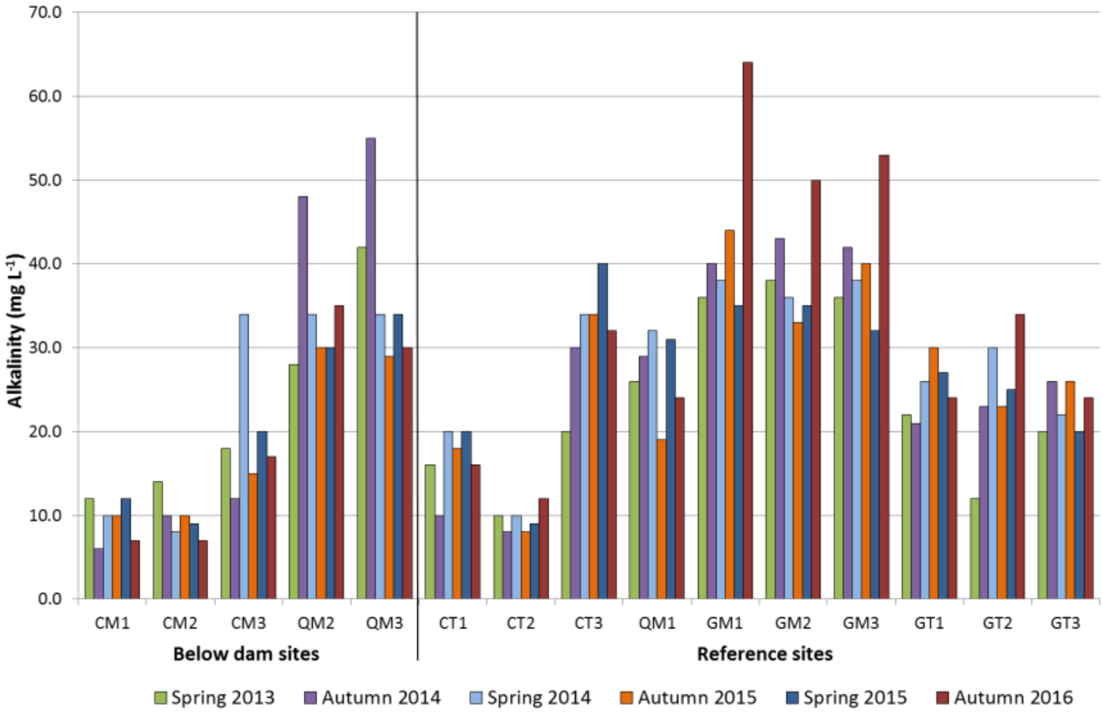
Nitrogen oxide concentrations at all sites from spring 2013 to autumn 2016. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for nitrogen oxide is shaded yellow.



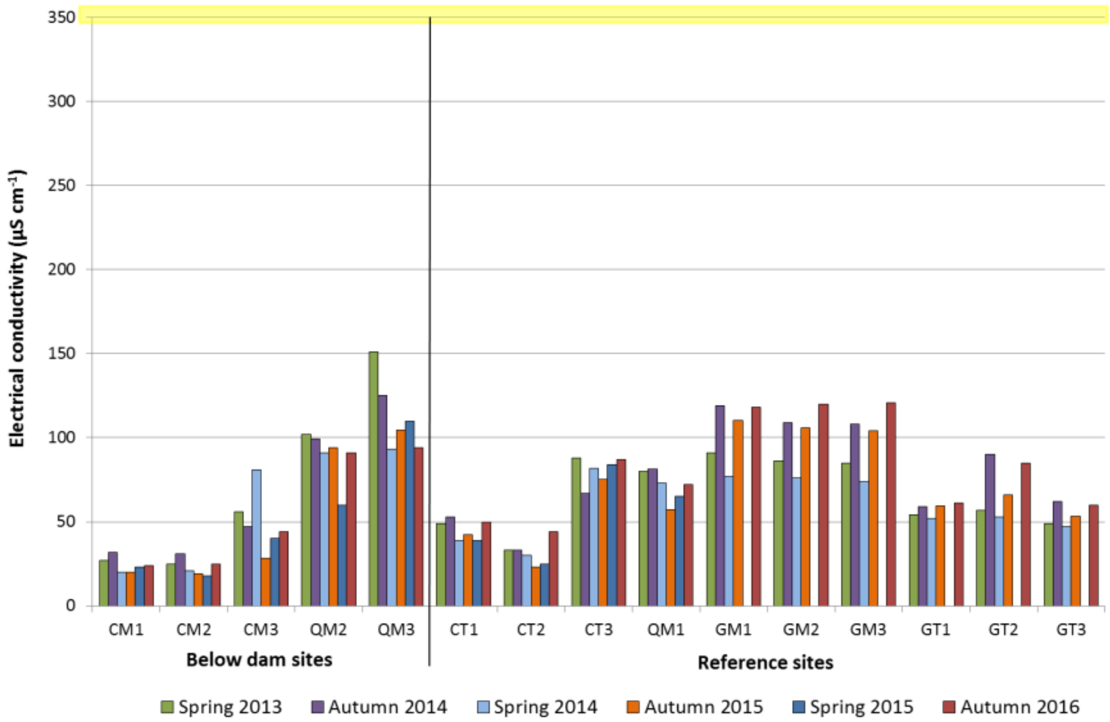
Total phosphorus concentrations at all sites from spring 2013 to autumn 2016. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total phosphorus is shaded yellow.



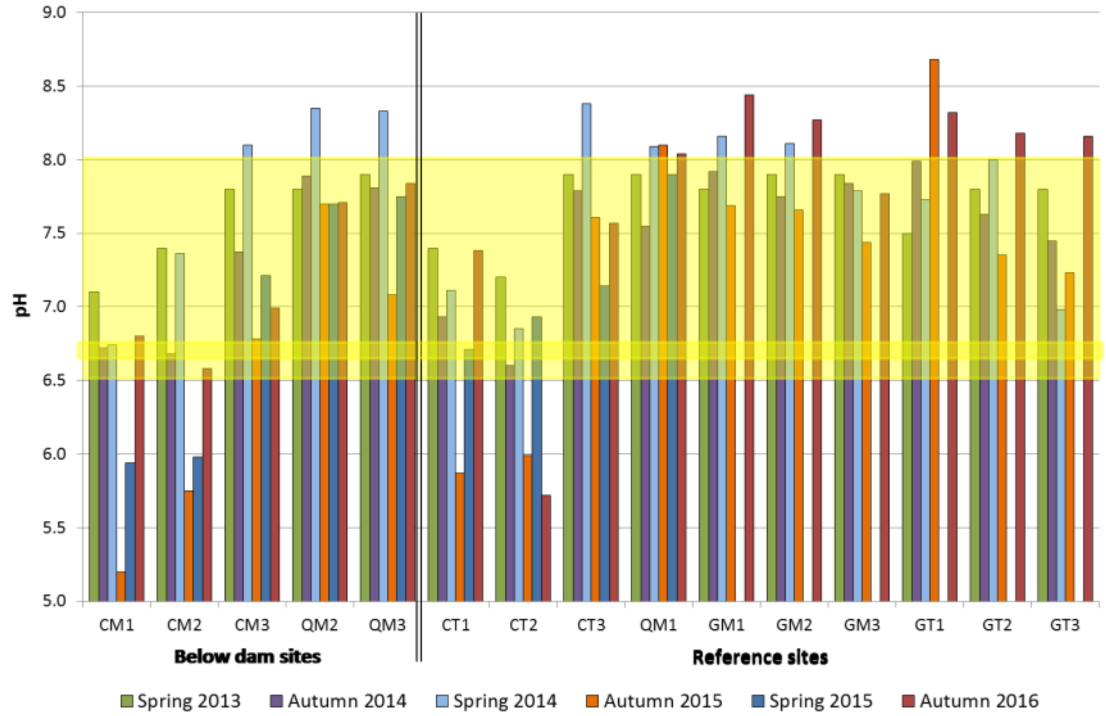
Total nitrogen concentrations at all sites from spring 2013 to autumn 2016. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total nitrogen is shaded yellow.



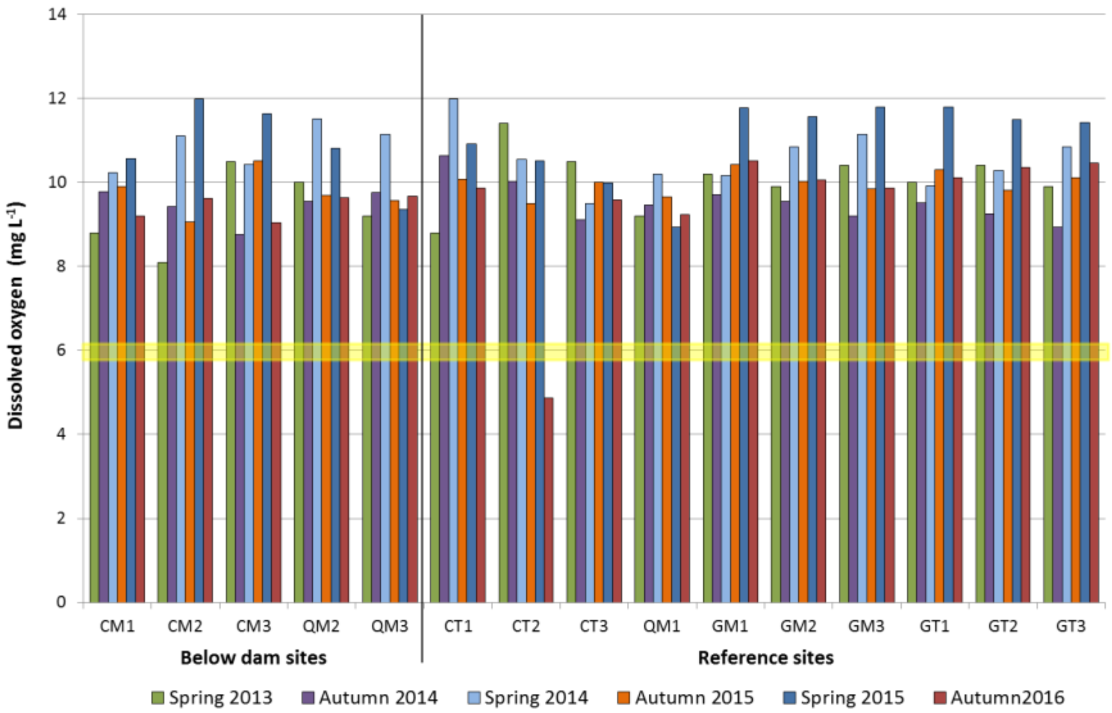
Alkalinity at all sites from spring 2013 to autumn 2016.



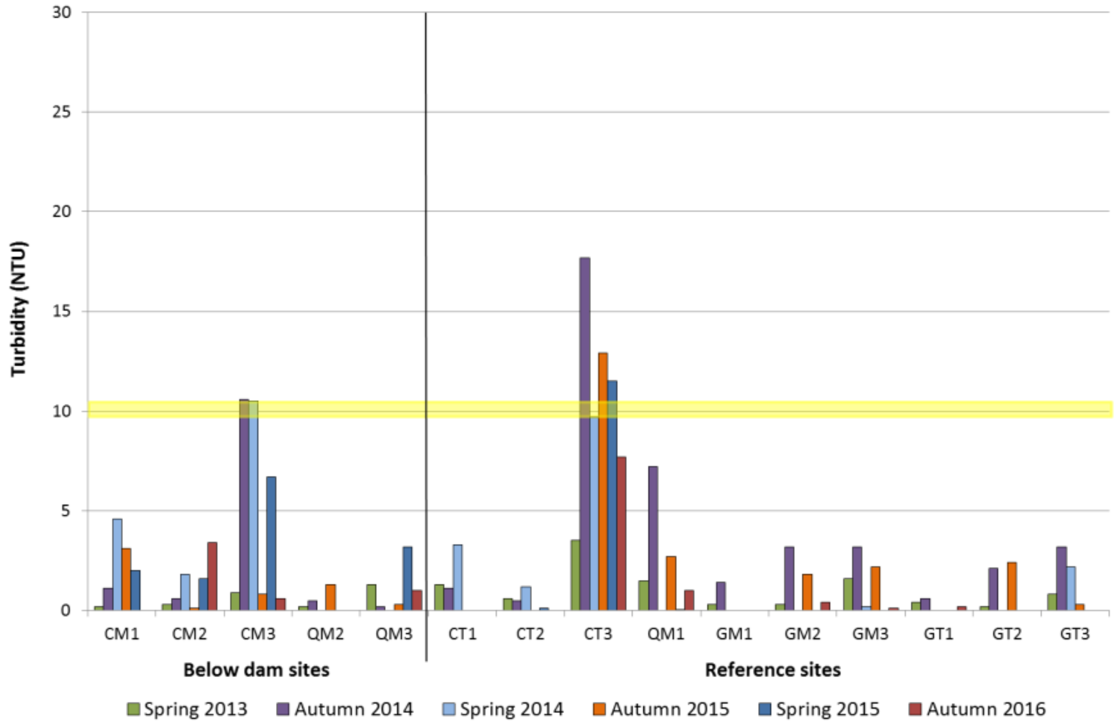
Electrical conductivity at all sites from spring 2013 to autumn 2016. The ANZECC/ARMCANZ (2000) guideline for electrical conductivity is shaded yellow.



pH at all sites from spring 2013 to autumn 2016. The ANZECC/ARMCANZ (2000) guideline for pH is shaded yellow.



Dissolved oxygen concentration at all sites from spring 2013 to autumn 2016. The minimum guideline for dissolved oxygen is shaded yellow (Environment Protection Regulation SL2005-38).



Turbidity at all sites from spring 2013 to autumn 2016. The guideline for turbidity is shaded yellow (Environment Protection Regulation SL2005-38).